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PENSOFT

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Tracking the spread of the northern bark beetle (*Ips duplicatus* [Sahlb.]) in Europe and first records from Switzerland and Liechtenstein

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Abstract

The northern bark beetle (*Ips duplicatus*), in Europe originally restricted to northern countries, expanded its distribution range to eastern Europe in the 20th century and is now causing considerable damage in spruce forests. In the past decades its presence has been confirmed in several Central European countries.

By means of pheromone traps and visual inspection of infested logs, in this study we demonstrate that *I. duplicatus* is also present in the Rhine valley in Switzerland and Liechtenstein. Breeding galleries with beetles and exit holes in an infested spruce log indicate that the trapped beetles had successfully developed in a local stand nearby.

An inquiry addressed to European entomologists was carried out to obtain information and references concerning the year of the first record or mention of *I. duplicatus* in their respective countries. This information substantiated the expansion of its historical range to the southeast in the middle of the last century and clearly showed recent movement westward, with Switzerland and Germany currently the westernmost countries where this species occurs. This recent range expansion is likely attributed to the transport of infested timber. The economic significance of this expanding bark beetle species is discussed in view of its co-occurrence with the notorious pest species *I. typographus*.

Key Words

double-spined bark beetle, global change, invasive species, range expansion, timber transport

Introduction

The northern bark beetle (*Ips duplicatus* (Sahlberg, 1836)) (Coleoptera, Curculionidae, Scolytinae), also known as the double-spined bark beetle, is originally native to Fennoscandia, Siberia and East Asia. Until recently, it occurred only rarely in eastern Europe (Pfeffer 1995; Duduman et al. 2013). Handschin (1963) mistakenly reported occurrences of this species in Canton Grisons, Switzerland in 1953, but the four specimens he collected were later re-identified as *I. amitinus* (Eichhoff, 1872) and *I. cembrae* (Heer, 1836) (Bovey 1987; Sanchez et al. 2020). In the past three decades, the northern bark beetle has become more frequent in eastern and southeastern European countries and is now present all over Central Europe. Recent outbreaks have been reported from Romania and Czechia (Olenici et al. 2009; Knížek and Liška 2018).

The northern bark beetle has a very similar biology to that of the notorious and widespread European spruce bark beetle (*I. typographus* (Linnaeus, 1758)) but is particularly adapted to the cool conditions of Fennoscandia and Siberia. The 3–4 mm long beetle produces a gallery system nearly identical to that of *I. typographus* but smaller and with up to five maternal galleries (John et al. 2019). Spring flight starts in April, usually a few days earlier than that of *I. typographus* (Duduman et al. 2013). The generation time of *I. duplicatus* is roughly two months, and, under Central European conditions, there

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are normally two generations produced per year, including sister broods. The populations usually overwinter as adults in the forest litter (Holuša et al. 2012; Petercord and Lemme 2019), but they can also overwinter in the tree phloem when low temperatures in fall prevent the last generation from completing its entire development before winter (Knížek 2019).

The primary host trees of *I. duplicatus* are various species of spruce (*Picea* spp.), and in Central Europe mainly Norway spruce (*Picea abies* (L.) Karst.). In outbreak situations, beetles are also found on *Pinus* and, in Siberia, occasionally on *Larix* (Pfeffer 1995; Duduman et al. 2013; Knížek et al. 2019). In a recent report, Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) were infested when beetle populations were large and Norway spruce was locally lacking (Kašák and Foit 2015). In endemic phases, *I. duplicatus* colonizes the uppermost part of the stem and the crown while *I. typographus* prefers the lower (Grodzki 2012). However, during outbreak phases, *I. duplicatus* also breeds in the lower stem parts.

The northern bark beetle has not previously been recorded in Switzerland. In 2008, preliminary trapping with two pheromone traps in the Rhine valley, Canton St Gallen, and in Birmensdorf, Canton Zurich, yielded no specimens of *I. duplicatus*. A pheromone trap survey in the Austrian state Vorarlberg in 2017 collected *I. duplicatus* within 1 km of the borders of Switzerland and Liechtenstein (Steyrer 2019). Our objective in this study was to determine whether this species was now established in these two countries. For this purpose, we set up pheromone traps and checked infested Norway spruce trees for the presence of this invasive bark beetle. We also conducted a literature search, made inquiries with entomologists in European countries, and searched national data bases to track this species' large-scale expansion.

Material and methods

In early April 2019 pheromone-baited Theyson® traps were installed in the Rhine valley 40 km upriver from Lake Constance at five locations in Canton St Gallen (Switzerland) and in the Principality of Liechtenstein (Table 1). The commercially available pheromone Dupliwit (Witasek, Feldkirchen, Austria) was used as a lure for *I. duplicatus*. At each location, one trap was placed near a spruce forest and close to transportation routes such as freeways, main roads and railroad tracks. Traps were emptied monthly until mid-August. In addition, random log piles with bark beetle-infested wood were visually checked for the presence of adult *I. duplicatus* in early November 2019.

The catches were morphologically and genetically identified to the species level. Morphological identification was done using the key of Pfeffer (1995). Comprehensive and well-illustrated compilations of the key characteristics for discriminating the closely related *Ips* species, i.e. *I. typographus*, *I. amitinus*, and *I. duplicatus*, can be found in Steyrer (2019) and Bussler (2020). The most typical feature is the ridge between spines 2 and 3 (Fig. 1). The sexes

Figure 1. Lateral view of a male *Ips duplicatus* showing the characteristic spines 2 and 3 on its declivity (photo: G. Cascia-no, WSL).

can be distinguished by the form of their spine 3 (Douglas et al. 2019). The morphological identification was verified by genetic analysis, applying a mini-barcoding technique to three specimens. To this end, a final sequence of 126 nu included in the cox1 gene was analyzed (Köppel et al. 2019). The sequences were looked up in the BLASTN suites of both the NCBI (http://www.ncbi.nlm.nih.gov) and the BOLDSYSTEMS (http://www.boldsystems.org) databases (accessed on 6 Dec. 2019). The mini-barcode reached an identification match of 99 % with the *Ips duplicatus* sequence JX263834 in all three cases.

In an attempt to document the spread of this species at the European level, we asked entomological experts from 27 countries for information on the first record of *I. duplicatus* in their countries (Table 2).

Results

Ips duplicatus was caught in each of the five traps placed in Switzerland and Liechtenstein, with a total of 420 specimens (Table 1; for a map see the 'info fauna' CSCF database: http://lepus.unine.ch/carto/23561). It was particularly frequent in the two northernmost traps in Altstätten and Rüthi. In most traps, this species was associated with substantial numbers of *I. typographus* (Table 1), some individuals of *Pityogenes chalcographus* (Linnaeus, 1760) and a few specimens of other bark and ambrosia beetle species (e.g. *Dryocoetes* spp., *Pityokteines* spp., *Trypodendron* spp., *Xylosandrus germanus* (Blandford, 1894)).

Visually searching for adult *I. duplicatus* in November revealed a wood pile with bark-beetle-infested logs near Rüthi. In one heavily infested Norway spruce log of 23 cm diameter, a few dead adults of *I. duplicatus* were found in galleries destroyed by maturation feeding. Successful breeding was indicated by the presence of numerous exit holes that were clearly too small to originate from *I. typographus*. The infested trees had been felled a few weeks earlier in a small mixed stand nearby, between the Rhine river and the freeway. These first records are already included in the recently published checklist of Scolytinae in Switzerland (Sanchez et al. 2020).

Table 1. Locations and catches of bark beetle traps baited with *Ips duplicatus* lures (18 April–8 August 2019).

Location	Swiss Grid x	Swiss Grid y	Latitude / Longitude	Elevation (m a.s.l.)	*I. duplicatus*	*I. typographus*
Altstätten CH	756000	248080	47.3651, 9.5040	830	194	22
Rüthi CH	758950	238420	47.2776, 9.5400	425	175	7
Gams CH	749700	229230	47.1972, 9.4144	780	5	19
Nendeln FL	759910	230460	47.2057, 9.5495	470	14	0
Schaan FL	759290	228790	47.1909, 9.5407	470	32	44
				Total:	420	92

Table 2. Year of the first record of *Ips duplicatus* in European countries, with corresponding sources.

Country	Year of 1st record/ mention	References	Remarks
Austria	1989	Holzschuh (1989), Steyrer (2019)	1 doubtful record from 1878
Belarus	1916	Escherich (1917), Aleksandrovicz and Galinovsky (1997)	
Belgium	absent	pers. comm. J.C. Grégoire	
Bosnia & Herzegovina	absent 1921	pers. comm. Mirza Dautbašić	no catches with pheromone baited traps
Bulgaria	absent	pers. comm. Daniela Kirilova	no catches with pheromone baited traps
Croatia	absent	pers. comm. Boris Hrasovec	no catches with pheromone baited traps
Czechia	1921	Wanka (1927)	
Denmark	absent	pers. comm. H.P. Ravn	
Estonia	1873	Seidlitz (1875)	
Finland	1834	Sahlberg (1836)	first description of species
France	absent	pers. comm. Fabien Soldati	
Germany	2013	according to records from Saxony; Bussler (2020)	
Baden-Wuerttemberg	2019	John et al. (2019)	
Bavaria	2018	John et al. (2019), Bussler (2020)	doubtful records from 1951
Brandenburg	2019	pers. comm. Kati Hielscher	
Saxony	2013	Bussler (2020)	
Great Britain	absent	pers. comm. Dave Williams	
Hungary	2019	pers. comm. Ferenc Lakatos	
Italy	absent	pers. comm. Massimo Faccoli	
Latvia	present*	pers. comm. Indrikis Krams; EPPO	
Liechtenstein	2019	this publication	
Lithuania	1923	Mastauskis (1925), Tamutis et al. (2011)	
Luxemburg	absent	pers. comm. A. Frantz	
Netherlands	absent	Naturalis biodiversity center; pers. comm. L.G. Moraal	
Norway	1921	Munster (1921)	
Poland	1912	Kleine (1912)	records from Silesia
Romania	1948	Duduman et al. (2013)	
Serbia	absent	pers. comm. Cedomir Markovic	
Slovakia	1920	Roubal (1941)	
Slovenia	absent	pers. comm. Roman Pavlin	
Sweden	1921	Spessivtseff (1921)	
Switzerland	2019	this publication	
Ukraine	1948	Nikulina et al. (2015)	

* year of 1st mention unknown

The inquiry addressed to European entomologists concerning the presence or absence and the first year of record of *I. duplicatus* showed a rather clear pattern of its range expansion (Table 2, Fig. 2). The oldest records originated from the late 19th and early 20th century from Fennoscandia, the Baltic states, Poland and, southernmost, Czechia and Slovakia, followed by Romania and the Ukraine in 1948. It was not until some 50–70 years later that it was found in more western countries, finally reaching the eastern part of Switzerland in 2019.

Discussion

Occurrence in Switzerland

The trap catches demonstrated that *I. duplicatus* has indeed arrived in Switzerland. In theory, these beetles could have emerged directly from timber transported from more eastern countries, such as Austria and Czechia, to Switzerland. The adult beetles found in a bark-beetle-infested bole from a nearby mixed forest stand, however, indicate that at least a local population has established in this part of the Rhine valley. Most likely, the source of the populations was infested timber imported into Switzerland, as several Swiss sawmills obtain un-debarked Norway spruce round wood from Austria and Czechia (Eidgenössische Zollverwaltung, pers. comm.). It might also be possible that beetles crossed the border by active dispersal or wind transport from the close Austrian Vorarlberg region, where it was detected in 2017 (Steyrer 2019).

The maximum catches in Switzerland were found at 830 m a.s.l. Most of the recent recordings of the northern spruce bark beetle in Central Europe were from lower elevations. This could be because i) the traps were intentionally placed along transportation routes, which are usually located at valley bottoms, ii) the beetles have not yet spread to higher elevations, or iii) this species is in

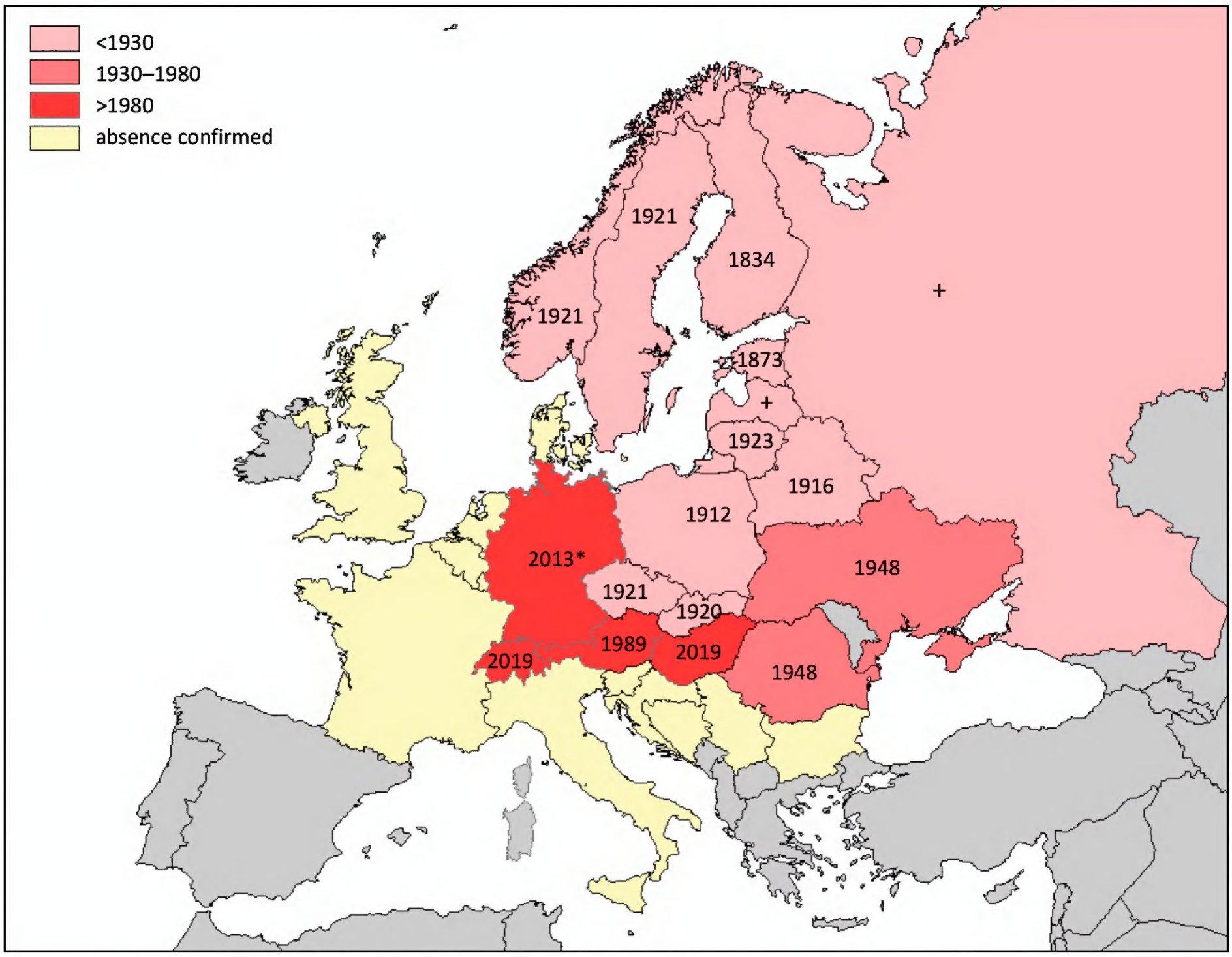

Figure 2. Map of European countries, with the corresponding year of the first record of *Ips duplicatus* (* see Table 2 for dates in individual regions of Germany).

fact restricted to lower elevations. *Ips duplicatus* seems to generally prefer elevations below approximately 1000 m a.s.l. (Holuša et al. 2010; Duduman et al. 2011), but it is regularly recorded at higher elevations as well (e.g. Knížek 2019).

It is quite likely that *I. duplicatus* has been present in Switzerland for a few years but has remained undetected; a single pheromone trap in 2008 in the same region did not catch any *I. duplicatus* beetles. Likewise, it may be more widespread in Switzerland than just in the Rhine valley, and expanded monitoring is planned to investigate this possibility.

Range expansion in Europe

The years of the first mention of *I. duplicatus* in European countries show a clear expansion of its distribution range (Fig. 2). The original southern border of its native distribution is thought to be northern Poland (Holuša et al. 2010). The large variation in the year of the first record in the Baltic countries, as well as in Norway and Sweden, can be attributed to differing intensities of entomological surveys and resulting publication activities in these countries, rather than actual movement of the northern bark beetle. A southward expansion to Central Europe was initially impeded by a barrier in Poland, consisting of a zone with almost zero spruce between two disjunct areas of the Norway spruce distribution (Boratyński 2007). This has probably hindered an easy exchange of the large northern and potential scattered southern populations of *I. duplicatus* (Grodzki 2012). Most likely, intensified transportation of infested logs bridged this barrier and the northern bark beetle arrived in the first decades of the 20th century in artificially established, susceptible spruce stands (Pfeffer and Knížek 1995). The subsequent findings in Romania and the Ukraine in 1948 are either the result of more extensive studies there or, more probably, the actual spread of the northern bark beetle to the southeast. The general impression of a southward movement of the northern bark beetle seems to be counterintuitive in view of climate change. Apart from the leap in Poland, the newer detections may be a consequence of the recent significant increase in large-scale bark beetle outbreaks in Poland, Czechia and Romania, which have drawn more attention to bark beetles. At least part of this damage is attributed to the northern bark

beetle (Knížek and Liška 2019; see section 'Economic Significance'). Also, pheromone lures for *I. duplicatus* have recently become commercially available and have facilitated detection and monitoring of this new species.

The range expansion of *I. duplicatus* to the west in the late 20th and early 21st century is undisputed. In the eastern part of Austria, which shares borders with the 'pseudo-endemic' countries Czechia and Slovakia, *I. duplicatus* was reported in 1989 and 2013 (Holzschuh 1989; Steyrer 2019). It continued to spread throughout the country and reached western Austria in 2017 (Steyrer 2019) and eastern Switzerland in 2019. Surprisingly, the movement of the northern bark beetle from Poland and Czechia to adjacent Germany seemed to take almost one century. There are some doubtful reports suggesting an earlier presence of this species in southeastern Germany (Bavarian forest), but they cannot be confirmed (Petercord and Lemme 2019). It was, however, recorded in western Czechia, close to the Bavarian and Saxon borders, already at the beginning of the Czech monitoring (Holuša et al. 2010). The long delay of its spread from the northern countries to Germany might be due to climatic reasons or, more likely, to deficient host trees along the expansion track and in the target country. However, scattered relict populations in the Alps cannot be completely ruled out (John et al. 2019). In 2003, the northern bark beetle was caught in pheromone traps in Belgium. This was clearly attributed to large volumes of spruce logs that were imported from Russia and the Baltic countries (Piel et al. 2006). The northern bark beetle has not yet established in Belgian forests (Table 2) and is also absent in Denmark, possibly because spruce is too infrequent in these regions, particularly in the east. To date, the northern bark beetle is absent from Italy, France, Benelux, Denmark, Great Britain, the Iberian Peninsula and most of the Balkans (Fig. 2, Table 2).

The obvious range expansion is most probably caused by the large-scale transportation of infested timber from more eastern countries. Most of the trap catches in western Austria and Switzerland originated from traps along transportation routes. In Baden-Württemberg, Germany, for example, the northern bark beetle was caught in significant numbers near sawmills processing infested un-debarked spruce timber imported from Czechia, but so far no infestations in adjacent forests have been observed (John et al. 2019). So far, the alpine barrier has prevented the southward expansion of this species to the Balkans and Italy, but, again, this barrier may be overcome by timber transportation.

Economic significance

In northern regions and under normal conditions, the northern spruce bark beetle has 1–2 generations and is a secondary colonizer of weakened trees. It can, under certain conditions, reach 3–4 generations and then become a primary pest (Holuša et al. 2010). Since the end of last and the beginning of this century, this beetle has become an invasive species in European Norway spruce forests (CABI 2019). More frequent disturbances and hotter droughts in recent years have caused the infestation of spruce trees by spruce bark beetles to skyrocket in several countries (Mezei et al. 2017; Knížek and Liška 2019). Most of this damage is caused by the notorious pest *I. typographus*. With the arrival of *I. duplicatus*, attributing spruce mortality to the causal agent has become more difficult because this species is most often accompanied by its congener *I. typographus* and by other spruce bark beetles (Grodzki 2012; Duduman et al. 2013; Å. Lindelöw, pers. comm.). Its very similar morphology, biology and infestation features make it difficult to discriminate from *I. typographus* in the field, even though its exit holes and gallery systems are markedly smaller.

Extensive outbreaks of *I. duplicatus* have been reported mainly in Czechia, Romania, Slovakia and Poland (Jakus 2001; Holuša et al. 2010; Olenici et al. 2011; Grodzki 2012; Duduman et al. 2013; Knížek and Liška 2019). In the northeastern part of Czechia, *I. duplicatus* was involved in up to 80 % of spruce infestations (Holuša et al. 2010). Most of the large-scale infestations were outside the natural range of Norway spruce, in young spruce plantations at low elevations, and in forests that were strongly weakened by e.g. drought and sawfly infestations (Olenici et al. 2009).

If *I. duplicatus* were always accompanied by *I. typographus*, it would be irrelevant for trees whether they are infested by *I. typographus* alone or by both bark beetle species; they are bound to die in any case. If, however, the northern bark beetle is able to colonize and eventually kill a substantial number of trees in its own right, this could lead to additional mortality in Norway spruce or other conifers. Moreover, the northern bark beetle often colonizes younger trees with thinner bark, in contrast to *I. typographus* (Duduman et al. 2013).

Another challenge associated with northern bark beetle infestations is that its management is more complex than for *I. typographus*. Most of all, sanitation fellings during winter are generally effective only against *I. typographus*, not against *I. duplicatus*, because the second generation of *I. duplicatus* leaves its brood trees in fall to overwinter in the litter layer. Additionally, *I. duplicatus* infestations occurring in tree crowns are more difficult to detect and, because of this beetle's faster larval development, the crowns often turn red only after the beetles have already left the trees (Holuša et al. 2010). Ultimately, the risk of future infestations by any bark beetle depends on climate and tree susceptibility rather than on the identity of the attacking bark beetle species.

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